Journal for Maritime in Community Service and Empowerment ISSN:
Vol. xx, No xx, Month-year

Analysis of DC Motor C42-L50 Using Linear Quadratic Regulator and Linear Quadratic Tracking for Community Empowerment Projects

* Yulian Fatkur Rohman[1], Anggara Trisna Nugraha[2], Rama Arya Sobhita[3]
[*1] Bio-Industrial Mechatronics Engineering, National Chung Hsing University, Taiwan
[2, 3] Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
*Correspondence author: g112040516@mail.nchu.edu.tw

Abstract: *This simulation represents a critical step in studying the waveform characteristics of the DC motor C42-L50 using a control system circuit with Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT). Prior to initiating the simulation and data collection, a mathematical model was formulated using the datasheet of the DC motor C42-L50. Based on this model, further analysis was conducted, followed by simulations using MATLAB Simulink to explore and evaluate the differences between LQR and LQT in terms of the waveform or graphical characteristics of the DC motor. The analysis involved observing the simulation scope in MATLAB Simulink and experimenting with noise introduced into the system circuit. To align this study with community empowerment objectives, the findings aim to enhance the reliability and efficiency of DC motor applications in community service projects. For instance, the improved motor control facilitated by LQR and LQT methodologies can support the development of renewable energy solutions, agricultural automation systems, or other local technological advancements. This approach underscores the practical benefits of integrating advanced control systems into projects that promote sustainable community development.*

Keyword: *DC Motor, Characteristic, Matlab*

Introduction

Technological advancements in this era of globalization have brought significant benefits to various aspects of life[1]. Human activities today are greatly influenced by developments in science and technology. With the rapid progress in technology, many tasks can now be completed more efficiently. In the industrial sector, system optimization plays a crucial role in maximizing the performance of systems or tools, ensuring resources are utilized without inefficiency[2][3].

One of the key approaches in system optimization involves control methods such as the Linear Quadratic Regulator (LQR) and Linear Quadratic Tracking (LQT)[4][5]. These techniques are particularly valuable when using a DC motor as a plant in the system, enabling users to achieve desired results such as specific RPMs or frequencies[6].

Understanding the basics of DC motors is essential before diving into control system design [7]. A DC motor requires a direct current voltage supply to its field winding to convert electrical energy into mechanical energy. The field winding, known as the stator, remains stationary, while the armature winding, called the rotor, rotates[8][9]. When the armature winding rotates within a magnetic field, an electromotive force (EMF) is induced, generating a voltage that alternates direction with each half rotation, effectively producing an alternating voltage[10][11]. To maintain unidirectional current flow, a commutator is used to reverse the phase of the voltage waveform, ensuring consistent energy delivery. The simplest form of a DC motor consists of a single-turn coil capable of rotating freely between the poles of a permanent magnet.

The application of LQR and LQT in controlling DC motors offers numerous advantages for community service projects[12]. These optimized control systems can enhance the efficiency and reliability of DC motors used in initiatives such as renewable energy generation, water pumping systems for rural areas, or small-scale manufacturing units. By integrating advanced technological solutions into such projects, communities can achieve sustainable development, improved productivity, and reduced operational costs, thereby amplifying the impact of community empowerment efforts.

Methodology

1. DC Motor

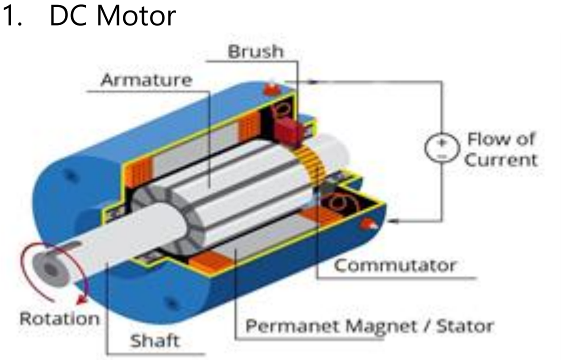

Figure 1. Dc motor

DC motors have two main parts, namely the stator and rotor. The stator is the non-rotating part of the motor, which consists of a frame and field windings[13]. While the rotor is the rotating part, this rotor part consists of an armature winding. These two main parts can be divided into several important components, namely yoke (magnetic frame), poles (motor poles), magnetic field coil (excitation coil), armature coil (excitation coil), anchor), switch (switch) and brush (brush/ carbon brush).

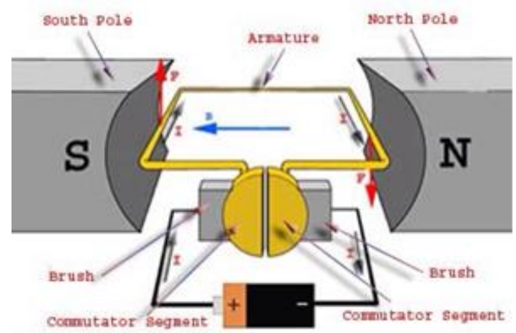

Figure 2. Principal dc motor

In principle, DC motors use electromagnetic phenomena to move[14]. If current is applied to the coil, the coil surface facing north will move towards the south magnetic pole and the coil facing south will move towards the north magnetic pole[15]. At this time, because the north pole of the coil meets the south pole of the magnet or the south pole of the coil meets the north pole of the magnet, an attractive force will occur which causes the coil's movement to stop.

DC Electric Motor or DC Motor This produces a number of revolutions per minute or usually known as RPM (Revolutions per minute) and can be made to rotate clockwise or counterclockwise if the electrical polarity given to the DC Motor is reversed[16]. DC Electric Motors are available in various rpm sizes and shapes. Most DC Electric Motors provide a rotational speed of around 3000 rpm to 8000 rpm with an operational voltage of 1.5V to 24V.

DC motors require a direct voltage supply to the field coil to be converted into mechanical energy. In a dc motor there are two coils, namely the field coil which functions to produce a magnetic field and the armature coil which functions as a place for the formation of electromotive force (emf E). If the current in the armature coil interacts with the magnetic field, a torque (T) will arise which will rotate the motor.

2. *Linear Quadratic Regulator* (LQR)

Linear Quadratic Regulator (LQR) is an optimization method for determining the input signal that will bring a linear system from an initial condition x(t0) to a condition x(t) that will minimize a performance index, namely the quadratic performance index. The advantage of using the linear quadratic formula is the ease of analysis and implementation[17]. Some problems that are usually solved using this method are the problem of time minimization, fuel minimization, etc. [18]. In the design of the Linear Quadratic Regulator (LQR) optimal control technique for regulating dc motor speed, optimization of the performance index is carried out by adjusting the Q matrix value, which can then produce an optimal feedback reinforcement matrix K and tracking matrix L for the performance index of the dc motor.

3. *Linear Quadratic Tracking* (LQT)

Linear Quadratic Tracking (LQT) is a control system designed to regulate its output so that it follows (tracks) a predefined trajectory specified through input signals. In the context of a quadrotor, the tracking process involves adjusting its altitude to align closely with the desired input response[19]. The system ensures that the quadrotor's altitude dynamics conform precisely to the given trajectory, minimizing deviations and optimizing control performance. This approach leverages advanced mathematical models and optimization techniques to achieve precise and efficient tracking, making it suitable for applications requiring high accuracy and stability in dynamic environments[20].

4. Specification motor

The following is the datasheet for the DC motor type C42-L50

C42 SERIES SPECIFICATIONS –

Part Number*		C42-L50		
Winding Code**		10	20	30
L = Length	inches	5.00		
	millimeters	127.0		
Peak Torque	oz-in	1100.0	1100.0	1100.0
	Nm	7.768	7.768	7.768
Continuous Stall Torque	oz-in	145.0	145.0	145.0
	Nm	1.024	1.024	1.024
Rated Terminal Voltage	volts DC	12 - 48	24 - 72	36 - 96
Terminal Voltage	volts DC	48	72	84
Rated Speed	RPM	3226	1885	1526
	rad/sec	338	197	160
Rated Torque	oz-in	80.3	98.2	126.7
	Nm	0.57	0.69	0.89
Rated Current	Amps	5.3	2.7	2.4
Rated Power	Watts	192	137	143
	Horsepower	0.26	0.18	0.19
Torque Senstivity	oz-in/amp	20	46	65
	Nm/amp	0.1412	0.3248	0.4590
Back EMF	volts/KRPM	14.8	34	48
	volts/rad/sec	0.1413	0.3247	0.4584
Terminal Resistance	ohms	0.7	4	5.7
Terminal Inductance	mH	1.3	6.6	13.5
Motor Constant	oz-in/watt^1/2	23.9	23.0	27.2
	Nm/watt	0.169	0.162	0.192
Rotor Inertia	oz-in-sec²	0.09	0.09	0.09
	g-cm²	6355.4	6355.4	6355.4
Friction Torque	oz-in	14.0	14.0	14.0
	Nm	0.10	0.10	0.10
Thermal Resistance	°C/watt	2.20	2.20	2.20
Damping Factor	oz-in/KRPM	5.25	5.25	5.25
	Nm/KRPM	0.037	0.037	0.037
Weight	oz	110	110	110
	g	3118	3118	3118
Electrical Time Constant	millisecond	1.8571	1.6500	2.3684
Mech. Time Constant	millisecond	22.28412	24.09974	17.2151
Speed/Torque Gradient	rpm/oz-in	-2.36486	-2.55754	-1.82692

Notes:
1. For MS (military style) connector, please specify connector housing and terminal.
2. Data for informational purposes only. Should not be considered a binding performance ag

Figure 3. Datasheet dc motor

5. Mathematic model

- Orde 1

For this 1st order method, it is hoped that researchers will find the 1st order transfer function equation of the C42-L50 DC motor. Based on the following equation (1), the formula or form of order 1 can be seen:

$$G(s) = \frac{K}{\tau s + K} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

K = Constant
τs = Torque

The constant itself can be found using the following formula:

$$K = \frac{\tau}{I} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

K = Constant
τ = Torque
I = Current

To get variable values starting from current and torque, researchers can look at the datasheet that has been determined in this research. In figure 2.2 above, it can be seen that the current in the 054B-2 DC motor is 1.7A and the torque itself is 0.052 Nm. After getting the values of current and torque, researchers can substitute them into equation (2).

After substituting into equation (2), you will get the value of K (constant). After that, the researcher can substitute it into equation (1) to get a value of order 1.

- Orde 2

For this next method, it is hoped that researchers can find the equation of order 2. And based on equation (3), the form or formula of order 2 can be identified, as follows:

$$G_{(s)} = \frac{\omega ns^2}{s^2 + 2\varsigma\omega ns + \omega ns^2} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

From equation (3) there is ς which is the symbol for the damping ratio and ω is the symbol for the angular velocity. For the damping ratio, the value can be seen in the data sheet, while for the angular velocity itself, it is not known in the data sheet, in other words, researchers are required to find the value of the angular velocity using the following equation:

$$\omega n = 2\ x\ \pi\ x\ f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

f = frequency

π = phi

After finding the results of the angular velocity using equation (4), researchers can enter the angular velocity value into equation (3). After that the value of order 2 can be generated.

After the researcher defines the LQR and LQT circuits, the next step is to carry out a circuit simulation to find out whether the previously determined equations match the simulation results. From the simulation results of the LQR and LQT circuits, researchers can analyze the simulation results using existing theory.

The next stage of research is to add noise to the series in order to see how good the plant the researchers are using is. If noise is added, the simulation results should produce graphs that are more reduced than those without using a plant

6. Modeling

In system optimization, after obtaining or determining the general modeling or formula, namely order 1 and order 2, researchers can apply the required DC motor data into the formula. The following is the calculation for order 1:

- 1st order mathematical calculations on the 054B-2 DC motor

  From equation (1) and equation (2) researchers can obtain a model as follows:

$$G(s) = \frac{0.03}{0.052 + 0.03}$$

To get the value of K, we need equation (2):

$$K = \frac{0.69}{1.7} = 0.405$$

After the calculation process using order 1 modeling is complete, the next step is the calculation using the MATLAB script:

```
% OPTIMASI SISTEM LQR PADA MOTOR DC
clear;
clc;
% Model Motor DC
J = 0.09 %J=momen inersia
b = 0.00349 %b=damping ratio
K = 0.3248 %K=Konstanta torsi(Kt)
R = 4 %R=resistansi
L = 6.6 %L=induktansi

A = [-b/J K/J; -K/L -R/L];
B = [0; 1/L];
C = [1 0]

AA = [ A zeros(2,1); -C 0];
BB = [B;0];

% Pole Placement
J = [-3 -4 -5];
K = acker(AA,BB,J);
KI = -K(3);
KK = [K(1) K(2)];

% Matrix LQR
Q = [1 0 0;
     0 1 0;
   0 0 1000];
   R = [1] ;
K_lqr = lqr(AA,BB,Q,R);
KI2 = -K_lqr(3);
KK2 = [K_lqr(1) K_lqr(2)];
```

a. LQR

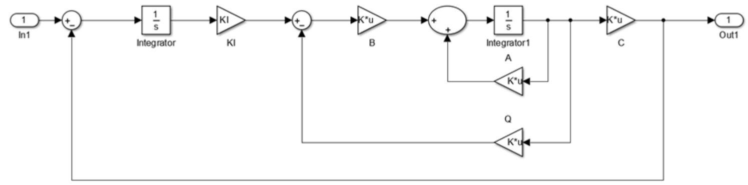

Figure 4. LQR Simulation

1. LQR without noise

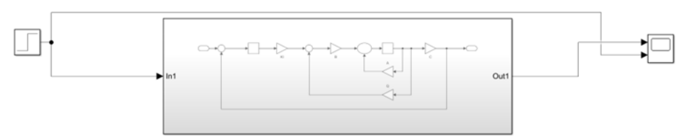

Figure 5. LQR without noise

2. LQR with noise

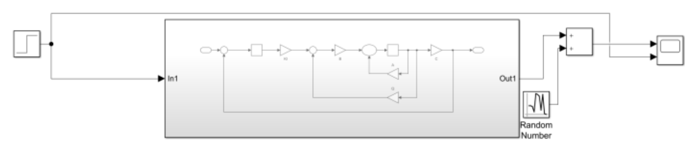

Figure 6. LQR with noise

Results and Discussions

1. LQR
   a. Without Noise

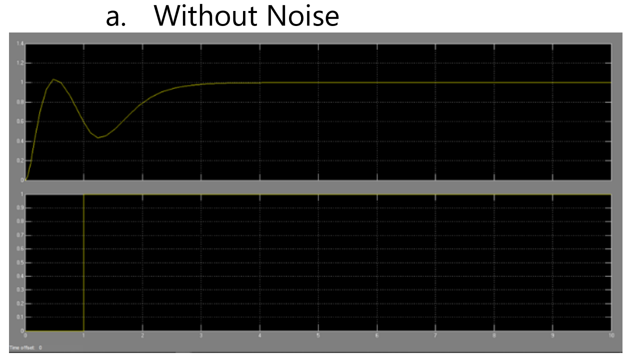

Figure 7. Graphic result LQR without noise

In Figure 7 you can see the results, namely two graphs. The bottom graph is the input or set point given to the system with the value one (1). Meanwhile, the top graph is the step response model value or result of the C42-L50 DC motor. The response value of the motor modeling steps using the LQT method reaches an amplitude of 1.001, and the time required for the results to reach a stable value is 4 seconds. The overstep in the results is 3646 n, while the understep in the LQR plot is without noise. is 55821%.

b. With Noise

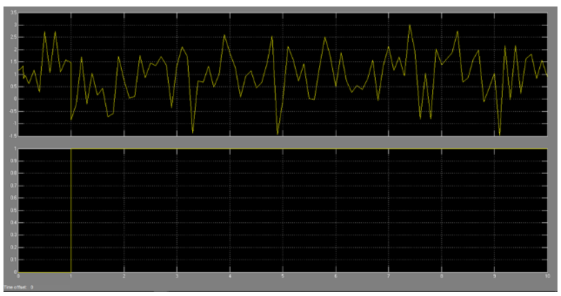

Figure 8. Graphic result LQR with noise

In Figure 8 you can see a result, namely two graphs. The blue bottom graph is the input value or set point given to the system which has a value of one (1). Meanwhile, the graph above is the value or result of the step response from the modeling of the C42-L50 DC motor. The value of the step response from the motor model reaches an amplitude of 1.98. The overshoot that occurred in the results was 49% and the undershoot that occurred in the LQR graph results without noise was 34%.

2. LQT
   a. Without Noise

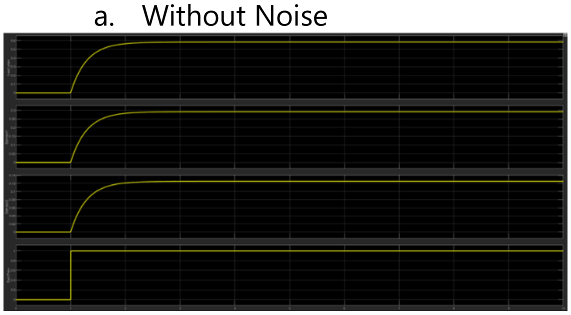

Figure 9. Graphic result LQT without noise

From the results of Figure 9, it can be seen that the bottom graph is the result of the value of the 1st order transfer function in the SIMO circuit. In the simulation results there are 4 graphs, namely the plant results graph, sensor1, sensor2, and set point. The results from the plant produce a stable value of 0.6 with the time required to reach the stable value being 2.5s. For sensor1 and sensor2, the time value or time to reach the same stable point is 2.5s, but the two sensors have different results or graphs. Sensor1 has a stable value of 0.3, while sensor2 has a stable value of 0.12.

Conclusion

From thetesting of the C42-L50 motor, it was observed that implementing the Linear Quadratic Regulator (LQR) method significantly improved the motor's response. This improvement is evident as the C42-L50 motor rapidly achieved the desired set point, demonstrating a faster and more precise response compared to scenarios without the LQR method. In cases where the LQR method was not applied, the motor's response deviated considerably from the desired set point and required a longer duration to achieve a steady state. These findings validate the theory that the LQR optimization technique effectively enhances the performance of DC motor responses.

However, when noise was introduced into the system, the LQR method exhibited limitations in maintaining optimal response performance. The response of the C42-L50 motor under LQR control, in the presence of noise, began to track the noise signals applied to the system. As a result, the response deviated from linearity, indicating susceptibility to disturbances. This highlights the need for additional measures, such as noise filtering or robust control strategies, to ensure the stability and reliability of the motor's performance in real-world conditions where noise is inevitable.

These findings have important implications for community service projects. The enhanced response characteristics of the DC motor using the LQR method can contribute to the development of reliable and efficient technological applications, such as renewable energy systems or automated tools in underserved communities. Addressing the limitations posed by noise would further strengthen the applicability of such systems in diverse community settings, ensuring consistent performance even under challenging conditions.

References

[1] Abdul Latif, A. Z. (2020). Motor DC PID System Regulator for Mini Conveyor Drive Based-on Matlab.

[2] Hafid, A. (2020). PERANCANGAN MODUL DATA AKUISISI PENGATURAN KECEPATAN MOTOR DC DENGAN MASUKAN DAC MENGGUNAKAN MATLAB. Vol 12 No1 2020.

[3] Muhammad, Arrofiq. (2021). Sistem Kendali Eddy Current Brakes Dinamomater menggunakan Linier Quadratic Regulator Vol. 9, No. 4, Oktober 2021 : 923 - 937, 937.

[4] Mohammed A. T. Alrubei, I. A. (2020). Capacity analysis & performance comparison of SISO, SIMO, MISO, MIMO system. Journal of Physics: Conference Series.

[5] Waroh, A. P. (2018). ANALISA DAN SIMULASI SISTEM PENGENDALIAN MOTOR DC. Volume 14 Nomor 2, Oktober.

[6] A. Gosh, S. Das, R. Mallipeddi, A. K. Das, and S. S. Dash, "A Modified Differential Evolution with Distance-based Selection for Continuous Optimization in Presence of Noise," IEEE Access, vol. 5, pp. 26944–26964, 2017, doi: 10.1109/ACCESS.2017.2773825.

[7] A. Ma'Arif, H. Nabila, Iswanto, and O. Wahyunggoro, "Application of Intelligent Search Algorithms in Proportional-Integral-Derivative Control of Direct-Current Motor System," J. Phys. Conf. Ser., vol. 1373, no. 1, 2019, doi: 10.1088/1742-6596/1373/1/012039.

[8] B. Guan, Y. Zhao, and Y. Li, "DESeeker: Detecting Epistatic Interactions Using a TwoStage Differential Evolution Algorithm," IEEE Access, vol. 7, pp. 69604–69613, 2019, doi: 10.1109/ACCESS.2019.2917132.

[9] Penaloza-Mejia, and G. Sepulveda-Cervantes, "Multi-Objective On-Line Optimization Approach for the DC Motor Controller Tuning Using Differential Evolution," IEEE Access, vol. 5, pp. 20393–20407, 2017, doi: 10.1109/ACCESS.2017.2757959.

[10] R. A. Sarker, S. M. Elsayed, and T. Ray, "Differential evolution with dynamic parameters selection for optimization problems," IEEE Trans. Evol. Comput., vol. 18, no. 5, pp. 689– 707, 2014, doi: 10.1109/TEVC.2013.2281528.

[11] W. Lianghong, W. Yaonan, Z. Shaowu, and T. Wen, "Design of PID controller with incomplete derivation based on differential evolution algorithm," J. Syst. Eng. Electron., vol. 19, no. 3, pp. 578–583, 2008, doi: 10.1016/s1004-4132(08)60123-1.

[12] Y. L. Li, Z. H. Zhan, Y. J. Gong, W. N. Chen, J. Zhang, and Y. Li, "Differential Evolution with an Evolution Path: A DEEP Evolutionary Algorithm," IEEE Trans. Cybern., vol. 45, no. 9, pp. 1798–1810, 2015, doi: 10.1109/TCYB.2014.2360752.

[13] L. U. Factor, "Congestion Management of Power System with Interline Power Flow Controller Using Disparity," vol. 1, no. 3, pp. 76–85, 2015M. G. Villarreal-Cervantes, A. Rodriguez-Molina, C. V. Garcia-Mendoza, O.

[14] Penaloza-Mejia, and G. Sepulveda-Cervantes, "Multi-Objective On-Line Optimization Approach for the DC Motor Controller Tuning Using Differential Evolution," IEEE Access, vol. 5, pp. 20393–20407, 2017, doi: 10.1109/ACCESS.2017.2757959.

[15] R. A. Sarker, S. M. Elsayed, and T. Ray, "Differential evolution with dynamic parameters selection for optimization problems," IEEE Trans. Evol. Comput., vol. 18, no. 5, pp. 689– 707, 2014, doi: 10.1109/TEVC.2013.2281528.

[16] Achmad, Irgi, and Anggara Trisna Nugraha. "Implementasi Buck-Boost Converter pada Hybrid Turbin Angin Savonius dan Panel Surya." Journal of Computer, Electronic, and Telecommunication (COMPLETE) 3.2 (2022).

[17] Febrianti, Chusnia, and Anggara Trisna Nugraha. "Implementasi Sensor Flowmeter pada Auxiliary Engine Kapal Berbasis Outseal PLC." Journal of Computer, Electronic, and Telecommunication (COMPLETE) 3.2 (2022).

[18] Ivannuri, Fahmi, Anggara Trisna Nugraha, and Lilik Subiyanto. "Prototype Turbin Ventilator Sebagai Pembangkit Listrik Tenaga Angin." Journal of Computer, Electronic, and Telecommunication (COMPLETE) 3.2 (2022).

[19] Jamil, M. H., et al. "The existence of rice fields in Makassar City." IOP Conference Series: Earth and Environmental Science. Vol. 681. No. 1. IOP Publishing, 2021.

[20] Syahdana, O. P., Syai'in, M., & Nugraha, A.T (2022). RANCANG BANGUN AUTOFEEDER DENGAN SISTEM NAVIGASI WAYPOINT DAN KENDALI KESTABILAN POSISI MENGGUNAKAN METODE FUZZY LOGIC. Jurnal Conference on

Automation Engineering and Its Application, 2. 261-269